X-rays at Sharp Focus: Chandra Science Symposium
*ASP Conference Series, Vol. **VOLUME**, 2002*
eds. S. Vrtilek, E. M. Schlegel, L. Kuhi

arXiv:astro-ph/0107469v1 24 Jul 2001

The Spectrum and Accurate Location of GRS 1758-258

William A. Heindl

Center for Astrophysics and Space Sciences, University of California, San Diego, La Jolla, CA 92093, U.S.A.

David M. Smith

Space Sciences Laboratory, University of California, Berkeley, Berkeley, CA 94720, U.S.A.

Abstract. We observed the "micro-quasar" GRS 1758–258 four times with *Chandra*. Two HRC-I observations were made in 2000 September-October spanning an intermediate-to-hard spectral transition (identified with *RXTE*). Another HRC-I and an ACIS/HETGS observation were made in 2001 March following a hard-to-soft transition to a very low flux state. The accurate position (J2000) of the X-ray source is RA = 18 01 12.40, Dec = −25 44 36.0 (90% confidence radius = $0''.6$), consistent with the purported variable radio counterpart. All images are consistent with GRS 1758–258 being a point source, indicating that any bright jet is less than ∼1 light-month in projected length, assuming a distance of 8.5 kpc. The March spectrum is well-fit with a multi-color disk-blackbody with an inner temperature of 0.50 ± 0.01 keV, interstellar absorption of $n_H = (1.59 \pm 0.05) \times 10^{22}\,\mathrm{cm}^{-2}$, and (un-absorbed) 1−10 keV luminosity of $4.5 \times 10^{36} (\mathrm{D}/8.5\,\mathrm{kpc})^2$ ergs s^{-1}. No narrow emission lines are apparent in the spectrum and upper limits to line equivalent widths are given.

1. Introduction

GRS 1758–258 and its sister source, 1E 1740.7–2942, were the first objects dubbed "micro-quasars". Their X-ray spectra are typical of Galactic black hole candidates (BHCs), and they are associated with time variable cores of double-lobed radio sources, reminiscent of extra-Galactic radio sources. This morphology, seen on a parsec scale within the Milky Way, earned them their nickname. GRS 1758–258 and 1E 1740.7–2942 are the brightest persistent sources in the Galactic bulge above ∼50 keV (Sunyaev et al., 1991). Their timing characteristics are typical of the black hole low/hard state (Main et al., 1999; Smith et al., 1997; Heindl et al., 1993; Sunyaev et al., 1991), and they consistently emit near their brightest observed levels, although they vary over times of days to years. Their X-ray emission properties are readily likened to the canonical BHC, Cyg X-1. In fact, together with Cyg X-1, they are the only known persistent, low-state BHCs, and all three sources have maximum luminosities around 3×10^{37}ergs s^{-1}. Radio jets have now been observed in Cyg X-1, furthering the similarity (Fender, 2000).

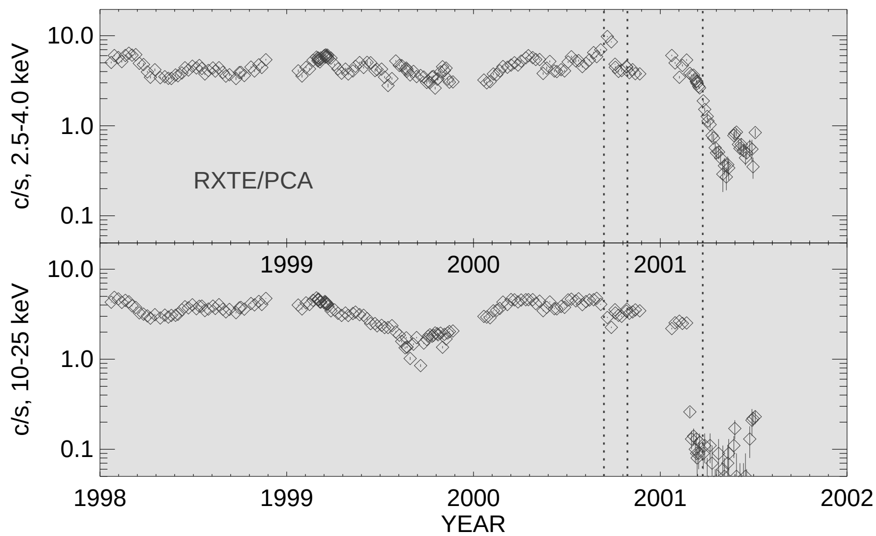

Figure 1. The *RXTE*/PCA light curve of GRS 1758–258 in two energy bands. Our *Chandra* observations (see Table 1) are indicated by dashed vertical lines. Observations 400163 and 400164 were made consecutively and so appear as a single line near 2001.2. The 1996-1997 flux history appears very similar to 1998 with the source remaining quite stable within a factor of $\sim$2.

GRS 1758–258 and 1E 1740.7–2942 are, however, quite different from the Galactic *superluminal* radio sources more typically thought of as micro-quasars: GRS 1915+105 and GRO J1655-40. The X-ray emission from these objects is much brighter and more spectacularly variable. Their radio jets, too, are much brighter and are highly variable, being unresolved or absent except during exceptional ejection events which last only weeks. In contrast, the radio lobes of GRS 1758–258 and 1E 1740.7–2942 are quite stable (Mirabel and Rodriguez, 1999).

Table 1. Observations

Seq. #	Date	Inst.	Exp. (ksec)	Rate (counts/s)
400085	2000 Sep 11.2	HRC-I	1	11.4
400131	2000 Oct 27.4	HRC-I	10	4.2
400164	2001 Mar 24.3	HRC-I	10	7.8
400163	2001 Mar 24.4	ACIS-S /HETGS	30	6.8[a]

[a]order 0 rate, significantly piled up

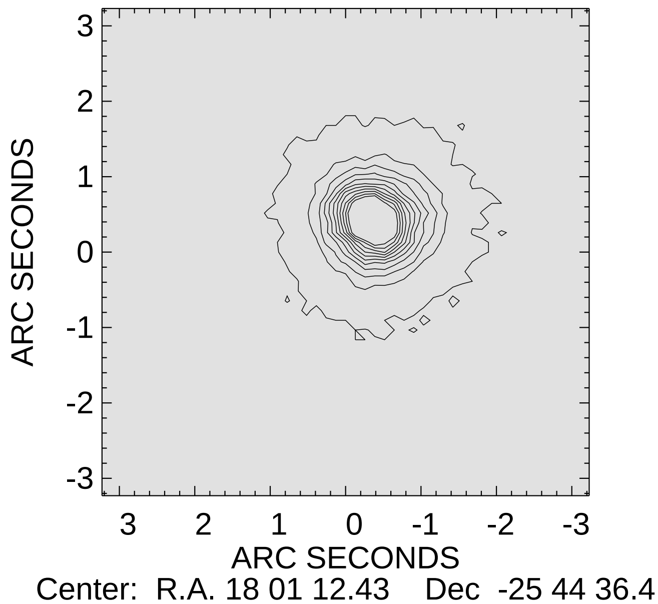

Figure 2. HRC-I image from observation 400131 centered on the indicated pointing direction. GRS 1758–258 appears point-like, with no indication of X-ray jets.

2. Observations

We observed GRS 1758–258 four times with *Chandra*. Table 1 lists the observation dates and durations. Two HRC-I observations were made in 2000 September-October spanning an intermediate-to-hard spectral transition (identified with *RXTE* Smith et al., 2001a,b). Another HRC-I and an ACIS/HETGS observation were made back-to-back in 2001 March following a dramatic hard-to-soft transition to a *very* low flux state. Figure 1. shows the *RXTE*/PCA light curve with our *Chandra* observations indicated.

3. Imaging and the Accurate Position

Figure 3. shows the HRC-I image from observation 400131. In this and the other HRC observations, the GRS 1758–258 image is consistent with the HRC point spread function, indicating that the source is point-like at the sub-arcsecond level. Assuming a distance of 8.5 kpc, this says that no strong jets are present on a physical scale of a light-month, the presence of arcminute scale radio jets notwithstanding. This is perhaps not surprising, as the timescale associated with producing the parsec-sized radio lobes would be years rather than months, and in fact the radio lobes are observed to be quite stable over years(Mirabel and Rodriguez, 1999). Thus, while de facto not ruled out, it is not required that a *persistent* small-scale X-ray jet be present to produce the observed radio lobes.

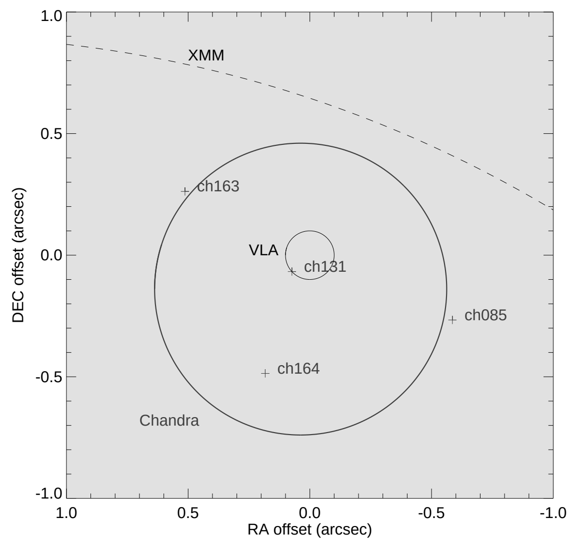

Figure 3. Error circles for GRS 1758–258. The 90% confidence *Chandra* error circle ($0''.6$ radius) includes the $0''.1$ VLA radio position of (source "VLA-C")(Marti et al., 1998). Coordinates are offsets from the radio position: (J2000) RA = 18 01 12.395, Dec = -25 44 35.90. The recent error circle from *XMM* is also indicated (Goldwurm et al., 2001).

Figure 3. shows the best fit source locations from our four *Chandra* observations as well as the estimated 90% confidence region derived from the average of the four positions. The ACIS-S/HETGS position (400163=ch163) was based on the zeroth-order image. While the image was significantly piled up, we expect a negligible effect on the position. The *Chandra* error circle is centered at (J2000) **RA = 18 01 12.40, Dec = −25 44 36.0** and has an estimated 90% confidence radius of $0''.6$ based on *Chandra*'s absolute aspect accuracy and averaging of four independent observations. The coincidence of the sub-arcsecond VLA and *Chandra* error circles seals the association of GRS 1758–258, the X-ray source, with the variable radio source ("VLA-C", Marti et al., 1998).

4. Spectrum

To reduce pile-up in the ACIS/HETGS observation, we used a 1/2 chip sub-array with a 1.7 s frame time. However, the counting rates in the MEG first order spectra were still about 2 counts/s, resulting in mild ($\lesssim 10\%$) pileup around 2 keV. For this presentation, we therefore restrict spectral fitting to the first order HEG spectra which did not suffer from pile-up. Figure 4. shows the HEG Order ±1 spectra rebinned to a minimum of 100 counts per bin. The data are well described by a multi-color disk-blackbody model and interstellar absorption (XSPEC: "phabs*diskbb"). The positive deviations above 4 keV are indicative

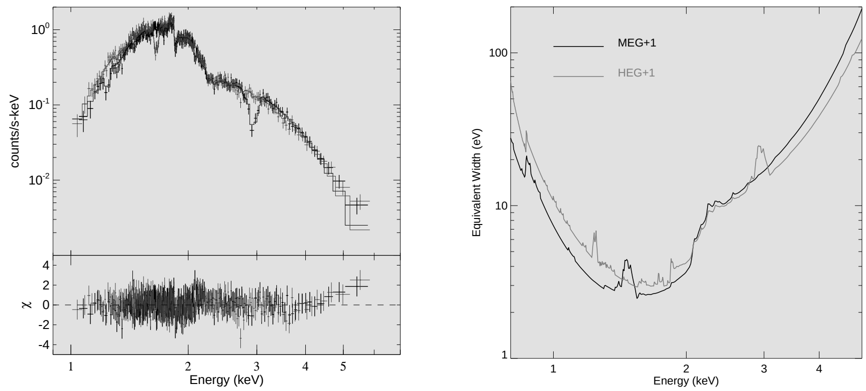

Figure 4. Left: The HEG first order spectra of GRS 1758–258 fit with a multi-color disk-blackbody spectrum and interstellar absorption. Right: The MEG and HEG order +1 sensitivity (5σ to narrow lines in the GRS 1758–258 spectrum.

of a weak power-law component (~2% of the $1-10$ keV unabsorbed flux) seen in joint fits with a contemporaneous *RXTE*/PCA ($3-15$ keV) observation. Table 2 lists the best fit parameters to the HEG spectra alone.

Preliminary inspection of both the HEG and MEG spectra showed no strong emission lines. Figure 4. shows the 5σ sensitivity to narrow emission lines. Because the GRS 1758–258 spectrum is so soft, the line sensitivity is a strong function of energy, varying by nearly two orders of magnitude between $1-5$ keV. The sensitivity was based on the best fit spectrum (see above) and the effective area of the ACIS/HETGS combination.

Table 2. Best fit absorbed disk-blackbody spectrum.

n_H ($\times 10^{21}$ cm^{-2})	15.9 ± 0.5
kT_{in} (eV)	505 ± 7
Flux (1–10 keV, ergs cm^{-2} s^{-1})	1.8×10^{-10}
χ^2_{red}/dof	0.66/544

5. Discussion

During more than 5 years' monitoring with the *RXTE* prior to 2001 March, the GRS 1758–258 hard X-ray spectrum was always dominated by a hard power law with photon index $\Gamma \sim 1.5-2.5$ (Smith et al., 2001a) with occasional appearance of a weak thermal component (Mereghetti et al., 1994; Heindl and Smith, 1998; Lin et al., 2000). As shown in Figure 1., GRS 1758–258 made an abrupt state change in 2001 March. The hard flux dropped by an order of magnitude in a few days, leaving the thermal component seen in Figure 4.. Based on relative luminosity, however, the current soft state is not a *high*/soft state. Rather it is

significantly less luminous than the low/hard state in this source. This can be contrasted to Cyg X-1 and the soft X-ray transients, where the *high*/soft state is more luminous. Rather, this seems to be a low-luminosity state which is fading into quiescence (Figure 1.). Finally, we note that the measured column density is consistent with previous measurements (Mereghetti et al., 1994; Lin et al., 2000; Goldwurm et al., 2001)

Since strong jet ejections are generally associated with the "very high state" and transitions from the "off" to high/soft states in X-ray transients (Fender, 2001), it is perhaps not surprising that no jet emission appeared in our low/hard state observations (Sep-Oct 2000) and the recent transition observation (Mar 2001). Perhaps our best opportunity will come when (if?) GRS 1758–258 makes a transition once again to its normal, low/hard state. We have an approved *Chandra* cycle 3 proposal to monitor the morphology of GRS 1758–258 and hope to observe a jet ejection.

References

Fender, R.: 2000, in *Rossi2000. March 22-24, 2000 at NASA/GSFC, Greenbelt, MD USA*, p. E87

Fender, R. P.: 2001, in *Proc. ESO Workshop (Garching, Sep 1999). L. Kaper, E.P.J. van den Heuvel, P.A. Woudt (eds.), Springer.*, p. 193

Goldwurm, A. et al.: 2001, astro-ph/0106310

Heindl, W. et al.: 1993, *ApJ* **408**, 507

Heindl, W. A. and Smith, D. M.: 1998, *ApJ* **506**, L35

Lin, D. et al.: 2000, *ApJ* **532**, 548

Main, D. et al.: 1999, *ApJ* **525**, 901

Marti, J., Mereghetti, S., Chaty, S., Mirabel, I. F., Goldoni, P., and Rodriguez, L. F.: 1998, *A&A* **338**, L95

Mereghetti, S. et al.: 1994, *ApJ* **433**, L21

Mirabel, I. and Rodriguez, L.: 1999, *ARA&A* **37**, 409

Smith, D. et al.: 1997, *ApJ* **489**, L51

Smith, D., Heindl, W., Markwardt, C., and Swank, J.: 2001a, *ApJL*, accepted, astro-ph/0103381

Smith, D., Markwardt, C., and Heindl, W.: 2001b, *IAU Circ.* **7595**, 1

Sunyaev, R. et al.: 1991, *ApJ* **383**, L49